A Comparison of Flexible and Rigid Ring Baffles for Slosh Suppression

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Introduction

THE stability of liquid-fuel-filled launch vehicles depends largely on the suppression of propellant sloshing. Many types of slosh suppression devices have been examined, and it has been found that ring baffles generally provide good damping characteristics.[1-4] To reduce the weight of the baffles, lightweight flexible baffles have been suggested. Stephens[5] presented data on the damping obtained from various flexible baffles in a rectangular tank and found that flexible baffles not only would be lighter but also would increase the liquid damping effectiveness. These interesting results led to the present studies of flexible ring baffles in a cylindrical tank.

Tank Configuration and Test Procedure

The experimental equipment and procedures utilized in the present work are similar to those employed in Ref. 6. Resultant liquid force on the tank wall, tank excitation amplitude, and liquid slosh height were recorded. The 17.75-in.-diam tank was made in two halves, each 17.75 in. long, with the baffles clamped between the flanges joining the tank halves. The damping and changes in natural frequencies were attributed only to the baffle, since in all these tests the bare wall tank (no baffle) damping was very small at the translational excitation amplitudes tested. The damping values in all cases were computed from the force-response curves by the half-bandwidth technique. For reference, a rigid baffle (made of $\frac{1}{8}$-in.-thick aluminum) was tested. The flexible baffles were made of Mylar plastic in four thicknesses: 0.002, 0.003, 0.005, and 0.0075 in. In every case, the ratio of the baffle width to tank radius was 0.157.

Results

Figure 1 shows damping ratio vs baffle depth for the rigid and the various flexible baffles for a single translation amplitude of $X_0/d = 0.00152$. The damping from the rigid baffle is slightly greater than that of the flexible baffles for baffle depths $0 < d_s/R \lesssim 0.025$, where d_s is the actual depth of the baffle below the undisturbed free surface, and R is the tank radius. However, for greater baffle depths the various flexible baffles are more effective; of these, the 0.002- and 0.003-in. Mylar baffles appear to be the most effective. Similar results are obtained for other excitation amplitudes. No rotational slosh was encountered in this particular series of tests; however, for larger excitation amplitudes, rotational slosh does occur for larger baffle submergence depths.

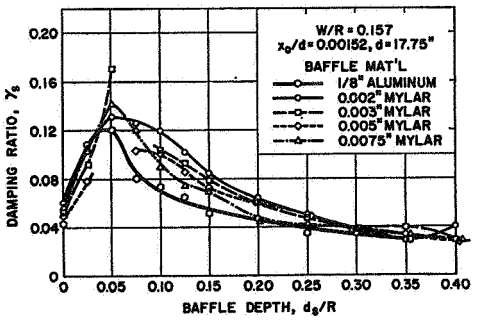

Fig. 1 Damping coefficients for rigid and various flexible baffles, excitation amplitude $X_0/d = 0.00152$.

If the liquid depth in the tank is at least as great as the tank diameter, the experimentally determined damping data for rigid ring baffles can be correlated with (i.e., are a function of) three dimensionless parameters: the ratio of the maximum wave height to the tank diameter (or alternatively, the excitation amplitude to the tank diameter); the ratio of the baffle submergence depth to the tank radius or diameter; and the ratio of the baffle width to the tank radius. These conclusions are also predicted by Miles' theory.[3] A dimensionless analysis for flexible baffles shows that one more parameter is needed here; the additional parameter is related to the flexibility of the baffle. For example, Stephens[5] correlated his data with the aid of a flexibility parameter defined as $F = (W/t)^3(1 - \mu^2)(\rho W^2/ET^2)$ where t = baffle thickness; W = baffle width; μ = Poisson's ratio; ρ = liquid density; E = modulus of elasticity; and T = period of slosh oscillation. He also used a period parameter P, but this parameter is equal to the already defined wave height-to-tank diameter parameter times the exponential function that accounts for the baffle depth.[3] In the present tests, a meaningful wave height could not be determined when the baffle was near the free surface (and for this reason the ratio of the excitation amplitude to tank diameter was used in place of the wave height parameter in most of our work), but in Fig. 2 curves are shown for the relative damping (flexible/rigid) parameter as functions of the period, flexibility, and baffle depth parameters for those cases in which the wave height could be measured. Each flexible baffle corresponds to one flexibility parameter in these plots; for example, the 0.003-in.-thick Mylar baffle corresponds to $F \approx 0.04$. The damping data for all of the baffles do correlate fairly well with these parameters.

Another flexibility parameter is the natural frequency Ω of the baffle in liquid (for the first antisymmetric ($\cos\theta$) mode) divided by the sloshing natural frequency. It was conjectured that the maximum damping would be provided by a baffle having a value of unity for this kind of flexibility parameter. To check this conclusion, the baffle natural frequency was computed by using hydrodynamic strip theory

Received December 16, 1966; revision received March 1, 1967. The results presented in this Note were obtained during research sponsored by NASA Marshall Space Flight Center under Contract NAS8-20290. More complete results are given in Technical Report 1, Contract NAS8-20290, Southwest Research Institute, August 1966. The authors thank Dr. Gordon L. Dugger for his considerable editing of the manuscript. [6.04, 7.09]

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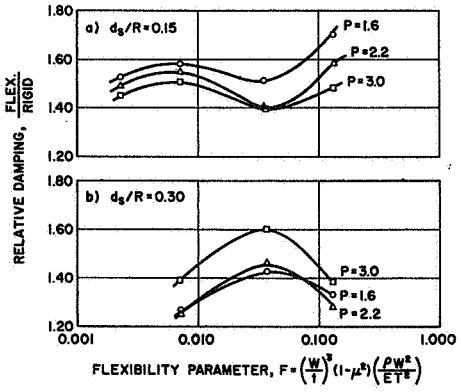

Fig. 2 Relative damping ratio vs flexibility parameter and period parameter: a) baffle submergence depth d_s/R = 0.15; b) baffle submergence depth d_s/R = 0.30.

and the elastic plate equation‡; the pertinent differential equation is

$$\frac{Et^3}{12(1-\mu^2)}\left[\frac{d^2}{dr^2}+\frac{1}{r}\frac{d}{dr}-\frac{1}{r^2}\right]^2 y - \Omega^2\left[t\rho_b + W\rho\left(1-\frac{r^2}{W^2}\right)^{1/2}\right] y = 0$$

where $y(r)\cos\theta$ is the assumed mode shape, ρ_b the baffle density and Ω the natural frequency of the baffle. This equation with appropriate boundary conditions was solved numerically, with the results shown in Fig. 3. According to this graph, the 0.003-in.-thick Mylar baffle has a natural frequency very close to the range of experimental slosh frequencies. From Fig. 2b, it can be seen that this baffle ($F \approx 0.04$) does indeed give the largest damping; however, this is true only for relatively large baffle submergence depths, as Fig. 2a shows that for shallower depths the more rigid baffles provide the highest damping. This last fact is even more clearly illustrated in Fig. 1.

Conclusions

In general, test results indicate that lightweight, flexible ring baffles provide damping about equal to or even better than similar rigid baffles. For baffles not too close to the free surface, the relative damping varies from an approximate value of 2 for small excitation amplitudes to a value slightly greater than 1 for larger amplitudes. The more flexible baffles provided the higher damping values (except when placed near the free surface) and also maintained a more constant liquid resonant frequency throughout the baffle depth range investigated. It appears to be logical to select a baffle whose natural frequency equals the sloshing natural frequency; such a baffle gives the best damping for deeply submerged baffles and gives fairly good damping characteristics for shallower submergence.

There is no question but that flexible baffles can reduce baffle weight by a considerable amount; however, the properties of the baffle material at cryogenic temperatures must be evaluated, and it may be necessary to investigate the stresses at the baffle inner edge to insure that tearing will not occur.

‡ This analysis was formulated by W.-H. Chu of Southwest Research Institute, to whom the authors express their appreciation.

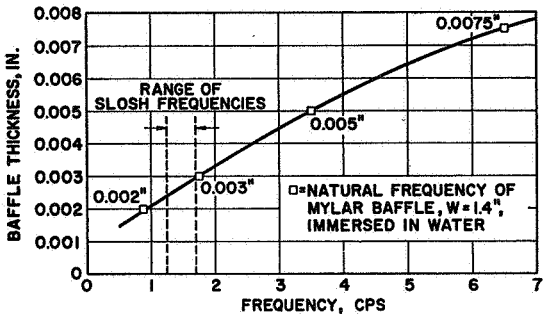

Fig. 3 Natural frequency of flexible baffle as a function of thickness.

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